Ulnar Shortening Osteotomy for Ulnar-Sided Wrist Pain

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Abstract

Background The purpose of ulnar shortening osteotomy is literally to shorten the ulna. It can tighten the triangular fibrocartilage complex (TFCC), ulnocarpal ligaments, and interosseous membrane. Nowadays, this method is used to treat ulnar-sided wrist pain, for which we have also started to use a treatment algorithm. The purpose of this study was to review the long-term and clinical results based on our algorithm.

Materials and Methods We retrospectively reviewed 30 patients with ulnocarpal impaction syndrome after a minimum follow-up of 5 years (Group A) and then retrospectively evaluated 66 patients with recalcitrant ulnar wrist pain treated based on our algorithm (Group B).

Description of Technique Ulnocarpal abutment was confirmed arthroscopically. The distal ulna was approached through a longitudinal incision between the extensor carpi ulnaris and flexor carpi ulnaris. We performed a transverse resection of the ulna fixed with a small locking compression plate. The contralateral side served as the reference for the length of shortening (mean, 2.4 mm; range, 1–5 mm). Disappearance of ulnar abutment was then confirmed again arthroscopically.

Results (Group A) Most patients showed good long-term clinical results. About half of the patients showed a bony spur at the distal radioulnar joint (DRUJ), but the clinical results did not significantly correlate with presence of bony spurs. Radiological parameters wre not related to the presence of bony spurs. **(Group B)** Twenty-four of the 66 patients investigated prospectively underwent an ulnar shortening osteotomy, with all showing good clinical results at 18 months postoperatively.

Conclusions Ulnar shortening osteotomy can change the load of the ulnar side of the wrist and appears useful for ulnar-sided wrist pain in the presence of ulnar impaction.

Level of evidence IV

Keywords
- ulnar shortening osteotomy
- ulnar-sided wrist pain
- TFCC
- DRUJ
- arthroscopy

The ulnar side of the wrist has been referred to as the "black box" of the wrist, and pathologies of this region have been compared with those of low back pain,[1,2] given the complex anatomy, myriad differential diagnosis, and varied treatment outcomes. Ulnar-sided wrist pain and arise from an acute traumatic injury or a chronic degenerative condition. Common causes of ulnar-sided wrist pain include isolated injuries to the triangular fibrocartilage complex (TFCC) or lunotriquetral ligament as well as ulnar impaction syndrome, which consists of a combination of these 2 conditions along with an

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ulnar positive variance.[2] Excessive impact stress between the ulna and carpal bones causes pain (ulnocarpal stress test). We recently developed an algorithm for the treatment ulnar-sided wrist pain[3] (►Fig. 1).

Milch described an ulnar shortening osteotomy for ulnocarpal impaction syndrome after distal radius fracture in 1941.[4] This procedure has been the standard treatment for ulnar impaction syndrome for many years.[5,6] Recent biomechanical studies have confirmed that an ulnar shortening osteotomy can improve the stability of the ulnar carpus and distal radioulnar joint (DRUJ).[7,8] As a result, this method is used for the treatment of ulnar-sided wrist pain, a common cause of upper-extremity disability,[2] and has achieved excellent results for posttraumatic TFCC injury and isolated lunotriquetral interosseous ligament (LTIL) tears.[9–11]

An ulnar shortening osteotomy can be performed when there is an ulnar positive variance. [12] Various authors have noted the utility of performing an extra-articular ulnar shortening osteotomy in the treatment of both degenerative and traumatic tears of the TFCC in patients with both an ulnar positive and neutral variance.[5,6,10,13–20] Shortening of the ulna obviously decreases the ulnar length and unloads the ulnar wrist, but it can also change the DRUJ morphology. Malalignment with respect to ulnar inclination and the sigmoid notch has been considered a relative contraindication for ulnar shortening osteotomy,[21] which might cause degenerative changes in the DRUJ.[22–24] Some types of DRUJ may be more susceptible to develop problematic incongruity after ulnar shortening osteotomy.[24]

We designed the present study to evaluate the long-term clinical results of ulnar shortening osteotomy to compare clinical results and radiological and arthroscopic findings. We assessed patients with ulnar-sided wrist pain who underwent ulnar shortening osteotomy based on our algorithm. Our hypothesis was that ulnar shortening osteotomy would achieve reasonable results.

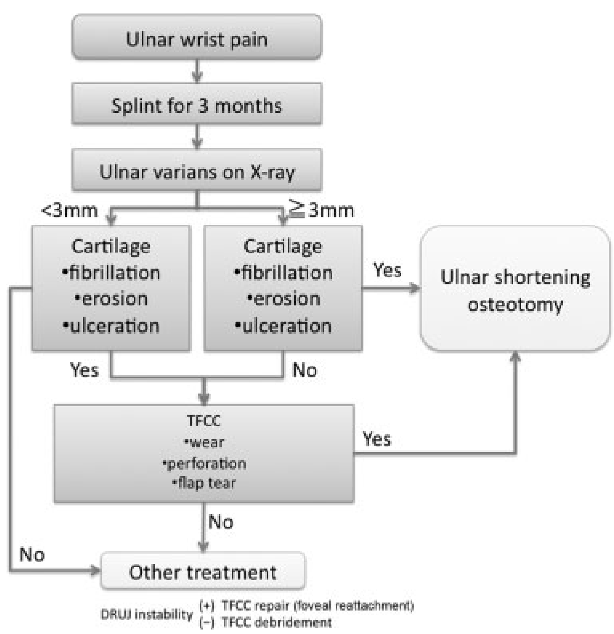

Fig. 1 Treatment algorithm for ulnar wrist pain. USO: ulnar shortening osteotomy, TFCC: triangular fibrocartilage complex, DRUJ: distal radioulnar joint. Cartilage grade: Grade I, chondromalacia, with or without swelling; Grade II, superficial fissures and erosions that do not reach subchondral bone; Grade III, deep fissures, down to subchondral bone; Grade IV, exposure of subchondral bone.

Materials and Methods

The institutional review board approved all study protocols. We obtained informed consent from all patients before surgery. This paper covers two studies.

Long-Term Clinical Assessment (Group A)

We retrospectively reviewed patients with ulnar impaction syndrome who had been observed postoperatively for a minimum of 5 years and who had undergone arthroscopic evaluations at the time of both ulnar shortening osteotomy and plate removal. Group A thus consisted of 30 patients were included in this study (18 right wrists, 12 left wrists; 15 men, 15 women). Mean age at the time of index surgery was 37 years (range, 16–64 years), and mean duration of follow-up was 11 years (range, 5–19 years). We confirmed the diagnosis of ulnar impaction syndrome by arthroscopy at the time of ulnar shortening osteotomy, as evidenced by chondral or osteochondral lesions on the ulnar side of the carpus (at least one lesion on the ulnar head, lunate, or triquetrum) in all cases. We diagnosed ulnar impaction syndrome if at least one osteochondral lesion was present on lunate or triquetrum or ulnar head.

Retrospective Cohort Study (Group B)

Records of all patients who had been treated between 2008 and 2010 in our hospital were collected. Group B thus consisted of 66 patients (36 male, 30 female). The mean age at the end of conservative treatment was 38.1 years (range, 15–67 years). We treated these patients based on our algorithm (►Fig. 1). Patients were allocated to undergo ulnar shortening osteotomy, arthroscopic TFCC repair (foveal reattachment), arthroscopic TFCC débridement, or prolonged conservative treatment. Twenty-four of the 66 patients underwent ulnar shortening osteotomy. We performed foveal reattachment arthroscopically.

Clinical Assessment

We obtained clinical data from medical charts. Range of motion and grip strength were assessed by therapists as independent observers both preoperatively (before ulnar shortening osteotomy and plate removal) and at follow-up. Every patient also completed the Hand20 questionnaire for self-assessment of residual disability in the hand and arm at final follow-up.[25] Patients treated based on our algorithm (Group B) were asked to complete the Hand20 independently before medical examination at each hospital visit for a minimum of 18 months. The Hand20 outcome questionnaire consists of 20 self-reported questions designed to measure upper extremity disability and symptoms, including a 10-point numeric rated scale for pain. Scores for the Hand20 range from 0 to 100, with lower scores indicating lower levels of disability.

Radiological Assessment

Using the wrist support developed by Nakamura et al,[26] we obtained a posteroanterior (PA) radiograph of the wrist with the shoulder in 90° of abduction, the elbow in 90° of flexion, the forearm in neutral rotation, and the wrist in neutral alignment. We measured ulnar variance (UV), sigmoid notch length, ulnar head inclination, and sigmoid notch inclination (►**Fig. 2**).[24] We measured UV to the nearest 0.5 mm using the method of perpendiculars. In addition, we evaluated bony spurs on plain radiography and recorded their locations (ulnar head or radial sigmoid notch). We compared pre- and postoperative radiographs to clarify the progression of spur formation and assess the time of spur formation from the operation.

Statistical Analysis

We analyzed pre- and postoperative wrist flexion–extension and grip strength using the Friedman nonparametric test and Wilcoxon rank-sum test. We used the chi-square test to determine the status of the TFCC and bony spurs. In bivariate analysis, we analyzed differences in clinical details such as evaluation of the TFCC and bony spur at the DRUJ and in radiological assessments using the Mann–Whitney U test. We used the Spearman rank correlation coefficient for clinical results and details. We performed multiple comparisons for the retrospective cohort study groups using the Bonferroni test or chi-square test when significant differences were detected. Student's *t*-test was used for comparison of preoperative Hand20 scores, pain scores, percentage grip strength, and wrist flexion–extension with those at each time point of postoperative follow-up.

We used a normality test to determine whether a dataset displayed a normal distribution. If the dataset could not be modeled by a normal distribution, we used the data after square root transformation or log transformation. We employed generalized linear models to identify correlations between clinical results and details. All variables are reported as mean ± standard deviation. The level of significance was set at $P < 0.05$. Missing values were circumvented using the last-observation-carried-forward method,[27] which assumes that after dropout, outcomes remained constant at the last observed value.

No external funding was utilized in this study.

Surgical Technique

We performed wrist arthroscopy before performing ulnar shortening osteotomy, providing a useful and final/reliable assessment of ulnar-sided wrist pain. Arthroscopy is considered the reference standard, and it identifies more lesions than arthrography does.[28] The hand was suspended with 3–5 kg of traction for arthroscopy, reduced to 2 kg for the ulnar shortening osteotomy procedure. We assessed the joint arthroscopically for the following: TFCC lesions, cartilage lesions, carpal instabilities, and synovitis. We also performed DRUJ arthroscopy with a technique that allowed us to confirm detachment of the TFCC at the fovea.[29] After ulnar impingement syndrome had been diagnosed, the extent of relative ulnar length was determined. Usually the contralateral side was referred to for determining the length of shortening. For patients with bilateral ulnar-positive variance, the amount of bone to be resected to obtain a final ulnar variance of 0 or 1 mm was determined from PA radiography. A 2- to 3-mm shortening was planned for patients with ulnar-neutral wrists.[30] If there were no chondral lesions an isolated TFCC débridement was performed regardless of the variance.

A lateral incision was made on the distal third of the ulna. A 5- or 6-hole small compression AO plate was then bent to fit the distal ulna, and two or three distal screws were drilled, tapped, and fitted with 2.7-mm screws (►**Fig. 3**). An AO

Fig. 2 Radiological evaluation. Ulnar variance (UV) was determined using the "project-a-line" technique. Ulnar head inclination is the angle between the longitudinal shaft of the ulna and the tangent to the ulnar head. Sigmoid notch inclination is the angle between the longitudinal shaft of the ulna and the tangent to the sigmoid notch of the radius. Sigmoid notch length is indicated by arrows. *Length of shortening = preoperative UV – postoperative UV.*

Fig. 3 Pre- and postoperative X-rays. A 5-hole AO tensioning-compression plate was used.

tensioning device was inserted proximally by drilling a hole and fitting a screw proximal to the plate. The site of osteotomy was marked and the plate was removed. A longitudinal mark was also made to ensure proper rotational alignment after osteotomy.[29] Efforts were made to minimize damage to the periosteum, to allow better bone healing. To avoid compromising DRUJ stability, the pronator muscle and interosseous membrane were left unstripped. The estimated section of ulna was resected. Subsequently, the plate was reinserted and the distal screws fixed. The tensioning device was placed, and compression of the osteotomy was performed. Finally, the proximal screws were fastened and the tensioning device was removed. With this technique, optimal compression was achieved and rotation of the distal ulna was prevented. After standard closure, an above-the-elbow cast was applied. Forearm rotation was prohibited for 4 weeks after surgery; then forearm rotation exercises were allowed with the change to a splint. Six weeks postoperatively, normal use of the wrist was permitted.

Results

Group A

Group A involved 30 patients. As long-term clinical results, mean Hand20 score was 10 (range, 0–64). Hand20 scores were 0 in 10 cases. Complications were rare, with only three patients reporting mild discomfort at the plate site. No patients underwent other procedures, such as for ulnar nonunion. Follow-up radiography revealed the appearance and progression of a bony spur at the DRUJ in 13 patients (►**Fig. 4**). Most bony spurs developed within 18 months postoperatively, but they did not significantly affect Hand20 and radiological measurements (►**Table 1**). We detected TFCC disc tear in 13 wrists at first-look arthroscopy with ulnar shortening osteotomy. Of these, 10 had healed by the time of second-look arthroscopy. The status of the TFCC and bony spur formation revealed no significant correlation. Hand20 score did not correlate significantly with the presence of bony spur or TFCC disc tear (►**Table 2**).

Only postoperative range of motion showed a normal distribution. With bivariate analysis, we identified a significant association between range of motion and age. We assessed range of motion with backward stepwise linear regression, which revealed that age alone explained 38% of the variability in postoperative range of motion ($R^2 = 0.375$; $P < 0.001$; $\beta = -0.63$). We identified generalized linear models and link functions for motion and grip strength, as well as Hand20 score. Bony spur formation and lower radial inclination were associated with decreased final grip strength. Male sex and advanced age were associated with lower Hand20 scores, whereas a long sigmoid notch and no TFCC tear were associated with higher Hand20 scores.

Group B

Group B involved 66 patients. Retrospective cohort study data are summarized in ►**Table 3**. We revealed better clinical results of ulnar shortening osteotomy compared with the TFCC débridement group. Within-group Hand20 and pain

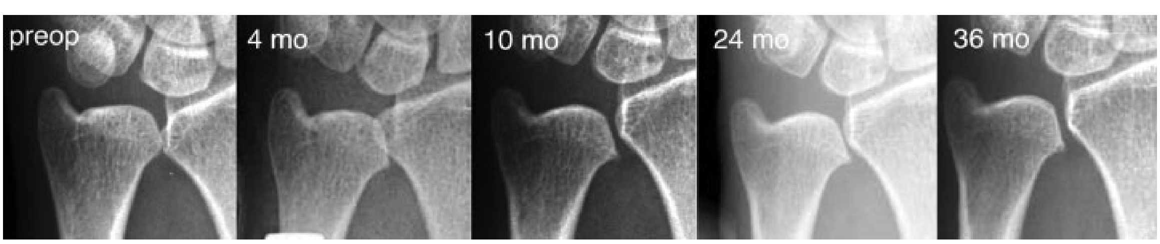

Fig. 4 Bony spur at DRUJ pre-operatively and at 4, 10, 24 and 36 months postoperatively.

Table 1 Group A. Bony spur and Hand20/radiological measurements

	Bony spur (+)	Bony spur (−)
Number	13	17
Age	40.8 ± 13.0	34.3 ± 11.5
Sex (male:female)	7:6	8:9
Hand20 score at final follow-up	8.1 ± 14.0	23.8 ± 22.4
Pre-op. ulnar variance (mm)	2.2 ± 1.4 (range, 1 to 5)	1.7 ± 1.5 (range, 0 to 6.5)
Post-op. ulnar variance (mm)	−0.5 ± 1.1 (range, −2 to 2)	−0.5 ± 1.4 (range, −2.5 to 3)
Length of shortening (mm)	2.7 ± 1.3	2.2 ± 1.2
Radial inclination (degrees)	26.9 ± 2.5	26.9 ± 6.6
Palmar tilt (degrees)	16.5 ± 2.4	13.9 ± 5.7
Sigmoid notch inclination (SNI) (degrees)	3.1 ± 8.9	2.6 ± 8.7
Ulnar head inclination (UHI) (degrees)	17.9 ± 8.3	16.1 ± 9.1
Angle (SNI – UHI) (degrees)	14.9 ± 7.3	13.5 ± 6.1
Sigmoid notch length (mm)	6.6 ± 1.4	6.7 ± 1.2

Table 2 Group A. TFCC tear at ulnar shortening osteotomy versus bony spur at final follow-up

Hand20 score: Number	Bony spur (−)	Bony spur (+)
TFCC tear (−)	13.5 ± 20.5: $n = 10$	13.9 ± 17.5: $n = 7$
TFCC tear (+)	8.8 ± 11.6: $n = 7$	1.4 ± 2.2: $n = 6$

No significant differences ($P = 0.387$; Hand20, $P = 0.785$; number).

score comparisons revealed significant decreases at 2 and 5 months or later, respectively ($P < 0.05$). Significant improvement in Hand20 score at 18 months was evident between the ulnar shortening osteotomy group and the TFCC débridement group ($P < 0.01$). A significant difference in pain score was seen between the ulnar shortening osteotomy and TFCC débridement groups at 18 months ($P = 0.01$). Once Hand20 and pain scores reached the level of significant difference, this significant improvement tended to be maintained thereafter in the ulnar shortening osteotomy group. Grip strength at 18 months was also significantly improved in the ulnar shortening osteotomy group, but not in the TFCC débridement and conservative groups. Two patients in the ulnar shortening osteotomy group used low-intensity ultrasound (SAFHS, Sonic Accelerated Fracture Healing System; Exogen, Piscataway, NJ, USA) to enhance bone union, and no

Table 3 Group B. Results from the retrospective cohort study

Hand20 score Pain score	2 months	5 months	12 months	18 months
Ulnar shortening osteotomy ($n = 24$)	46.5 ± 20.9	23.0 ± 15.9	11.3 ± 11.2	8.7 ± 8.1
	4.1 ± 2.1	2.6 ± 1.8	1.4 ± 1.1	1.5 ± 1.6
TFCC repair ($n = 15$)	46.6 ± 29.9	20.4 ± 12.5	14.5 ± 10.9	10.8 ± 9.7
	3.0 ± 1.1	2.6 ± 0.7	1.8 ± 1.7	2.3 ± 1.8
TFCC débridement ($n = 14$)	27.4 ± 19.0	23.3 ± 19.3	24.9 ± 14.0	25.8 ± 17.4
	3.3 ± 1.8	3.3 ± 1.8	2.9 ± 1.3	3.4 ± 1.5
Conservative treatment ($n = 13$)	26.0 ± 21.8	19.2 ± 20.8	15.0 ± 15.6	15.7 ± 20.4
	3.7 ± 2.6	3.5 ± 2.7	3.2 ± 2.9	2.4 ± 2.3

cases underwent secondary surgery except for removal of plates.

Plate removal and arthroscopy is performed at the discretion of the patient. We know that there are marked differences in patient attitudes toward plate removal between countries. In Japan, most patients do not want to keep any foreign materials in their body, if at all possible. Thanks to a universal health coverage system, costs for plate removal and second-look arthroscopy are much less expensive in Japan than in countries without universal health coverage. We think that this partly explains the significant difference in patient attitudes toward the operation. We did not pressure patients to undergo second-look arthroscopy.

Discussion

Ulnar shortening osteotomy is literally a procedure that shortens the ulna, which is the rationale for its use in ulnocarpal impaction syndrome.[31] Ulnar variance affects the load distribution of the wrist. Larger ulnar variance increases the load on the ulnar carpus.[23,32] However, ulnocarpal impaction syndrome can also occur in ulnar neutral and negative wrists because of the inverse relationship between ulnar variance and TFCC thickness[33] and because ulnar variance changes with forearm rotation and dynamic ulnar impaction occurs as a result of relative lengthening of the ulna with pronation and forced finger flexion.[2] The diagnosis should therefore be made only after careful physical examination including tests such as the ulnocarpal stress test. We have started using a treatment algorithm, and the present study showed good results after ulnar shortening osteotomy. Surgical treatment for ulnocarpal impaction syndrome is based on decompression of the ulnar side of the wrist joint. Two surgical treatment options are available for ulnar impaction syndrome: ulnar shortening osteotomy and either an open or an arthroscopic wafer procedure. The wafer procedure is much easier to perform than an ulnar shortening osteotomy[34] and may be performed arthroscopically. Tomaino[34] reported satisfactory results for ulnar impaction syndrome. In addition, the wafer procedure avoids the risk of nonunion and plate-related complications.[15] However, the articular cartilage surface of the distal ulna is damaged.

On the other hand, biomechanical studies have shown that ulnar shortening osteotomy also tightens the ulnar collateral ligaments, the extensor carpi ulnaris tendon sheath, and the radioulnar ligaments.[8,9,19] A recent report also revealed the importance of the interosseous membrane, and ulnar shortening osteotomy can improve the stability of the DRUJ.[7] The palmar radioulnar ligament forms the proximal attachment point for the ulnolunate and ulnotriquetral ligaments. Ulnar shortening osteotomy can tense these ligaments and stabilize the lunotriquetral joint.[2] Therefore, after an ulnar shortening osteotomy, the load at the ulnar carpus is decreased and stability of the distal radioulnar joint is improved.[7,8] The ulnocarpal joint is thus unloaded and wrist pain relieved not only in ulnocarpal impaction syndrome, but also in TFCC injury and lunotriquetral (LT) injury. In addition to the reduced load transmitted through the ulnar wrist column, improved stability of the DRUJ as induced by ulnar shortening might exert favorable effects on repair of the torn TFCC.[35]

Other advantages of ulnar shortening osteotomy are the maintenance of the cartilage surface at the distal ulna and the simplicity of the procedure without bone grafting.[20,36–38] The disadvantages of ulnar shortening are nonunion/delayed union and hardware irritation.[6,10,15,17–19] However, rates of complication can be low if the procedure is properly performed,[5,38] and many papers have actually reported low complication rates.[31,39] New devices to assist with ulnar shortening osteotomy may further reduce the risk of nonunion.[17,19] Several authors have suggested oblique osteotomy[4,10] and step-cut distal ulnar shortening osteotomy,[40] whereas others have performed transverse osteotomy because of its versatility and technical simplicity.[15] Application of low-intensity pulsed ultrasound shortened the time to cortical union by 27%, and to endosteal union by 18%.[41]

Plate removal may be necessary because of discomfort or other reasons. Although the time of greatest risk of bone refracture is shortly after hardware removal, how long this state persists remains unclear,[42,43] but the incidence of refracture is low. Werner et al showed that load distribution pattern changes in the radius and ulna depending on UV.[44] After ulnar shortening osteotomy, load moves to the radius from the ulna. This may also explain the low refracture rate after early plate removal. In any case, it is important that no plates are removed until the surgeon confirms that the osteotomy has healed on sequential radiography.[45] Newer, low-profile plates and volar placement of the plate can greatly decrease the incidence of hardware removal.[46]

Ulnar shortening osteotomy has few contraindications. Absolute contraindications include established DRUJ arthritis and dorsal DRUJ dislocation. Ulnar shortening osteotomy decreases the load on the ulnar carpus and may cause degenerative changes in the DRUJ.[22] Some reports have described malalignment in the DRUJ as a relative contraindication for ulnar shortening osteotomy,[21] due to the risk of degenerative changes.[22–24] Although about half of patients showed development of a bony spur at the DRUJ in this study, no radiological parameters correlated with spur formation. We do not consider a reversed obliquity of the sigmoid notch as a contraindication for ulnar shortening osteotomy.

Several studies have reported a high percentage of success with ulnar shortening osteotomy.[20,30,37–39] Combining the results using standard technique and equipment, 79 of 90 patients (88%) achieved good or excellent results regarding pain relief and recovery of function, with only one nonunion (1%).[5,9,14,18] Poor outcomes were associated with degenerative changes at the DRUJ, long duration of symptoms, smoking, and workers' compensation claims.[13,47] The present study likewise showed good results, due to the proper diagnostic process applied. We believe that our algorithm is applicable for ulnar wrist pain. The results of ulnar shortening osteotomy have been mixed,[48] and a prospective study is warranted to clarify factors affecting the clinical results.

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Ethical Approval
The institutional review board approved all study protocols.

Location where the work was performed
Department of Hand Surgery, Nagoya University School of Medicine, Nagoya, Japan

Conflict of interest
None

References

1 Palmer AK. The distal radioulnar joint. Orthop Clin North Am 1984;15(2):321–335
2 Sachar K. Ulnar-sided wrist pain: evaluation and treatment of triangular fibrocartilage complex tears, ulnocarpal impaction syndrome, and lunotriquetral ligament tears. J Hand Surg Am 2008;33(9):1669–1679
3 Nishizuka T, Tatebe M, Hirata H, Shinohara T, Yamamoto M, Iwatsuki K. Simple debridement has little useful value on the clinical course of recalcitrant ulnar wrist pain. Bone Joint J 2013; 95-B(12):1687–1696
4 Milch H. Cuff resection of the ulna for malunited Colles' fracture. J Bone Joint Surg Am 1941;23(2):311–313
5 Chun S, Palmer AK. The ulnar impaction syndrome: follow-up of ulnar shortening osteotomy. J Hand Surg Am 1993;18(1): 46–53
6 Loh YC, Van Den Abbeele K, Stanley JK, Trail IA. The results of ulnar shortening for ulnar impaction syndrome. J Hand Surg [Br] 1999; 24(3):316–320
7 Moritomo H. The distal interosseous membrane: current concepts in wrist anatomy and biomechanics. J Hand Surg Am 2012;37(7): 1501–1507
8 Nishiwaki M, Nakamura T, Nakao Y, Nagura T, Toyama Y. Ulnar shortening effect on distal radioulnar joint stability: a biomechanical study. J Hand Surg Am 2005;30(4):719–726
9 Darrow JC Jr, Linscheid RL, Dobyns JH, Mann JM III, Wood MB, Beckenbaugh RD. Distal ulnar recession for disorders of the distal radioulnar joint. J Hand Surg Am 1985;10(4):482–491
10 Boulas HJ, Milek MA. Ulnar shortening for tears of the triangular fibrocartilaginous complex. J Hand Surg Am 1990;15(3): 415–420
11 Mirza A, Mirza JB, Shin AY, Lorenzana DJ, Lee BK, Izzo B. Isolated lunotriquetral ligament tears treated with ulnar shortening osteotomy. J Hand Surg Am 2013;38(8):1492–1497
12 El-Karef E. Staged reconstruction for malunited fractures of the distal radius. J Hand Surg [Br] 2005;30(1):73–78
13 Bernstein MA, Nagle DJ, Martinez A, Stogin JM Jr, Wiedrich TA. A comparison of combined arthroscopic triangular fibrocartilage complex debridement and arthroscopic wafer distal ulna resection versus arthroscopic triangular fibrocartilage complex debridement and ulnar shortening osteotomy for ulnocarpal abutment syndrome. Arthroscopy 2004;20(4):392–401
14 Chen NC, Wolfe SW. Ulna shortening osteotomy using a compression device. J Hand Surg Am 2003;28(1):88–93
15 Constantine KJ, Tomaino MM, Herndon JH, Sotereanos DG. Comparison of ulnar shortening osteotomy and the wafer resection procedure as treatment for ulnar impaction syndrome. J Hand Surg Am 2000;25(1):55–60
16 Minami A, Ishikawa J, Suenaga N, Kasashima T. Clinical results of treatment of triangular fibrocartilage complex tears by arthroscopic debridement. J Hand Surg Am 1996;21(3):406–411
17 Mizuseki T, Tsuge K, Ikuta Y. Precise ulna-shortening osteotomy with a new device. J Hand Surg Am 2001;26(5):931–939
18 Wehbé MA, Cautilli DA. Ulnar shortening using the AO small distractor. J Hand Surg Am 1995;20(6):959–964
19 Rayhack JM. Ulnar shortening. Tech Hand Up Extrem Surg 2003; 7(2):52–60
20 Tatebe M, Nakamura R, Horii E, Nakao E. Results of ulnar shortening osteotomy for ulnocarpal impaction syndrome in wrists with neutral or negative ulnar variance. J Hand Surg [Br] 2005;30(2): 129–132
21 Hollevoet N, Verdonk R, Van Maele G. The influence of articular morphology on non-traumatic degenerative changes of the distal radioulnar joint. A radiographic study. J Hand Surg [Br] 2006; 31(2):221–225
22 Köppel M, Hargreaves IC, Herbert TJ. Ulnar shortening osteotomy for ulnar carpal instability and ulnar carpal impaction. J Hand Surg Br 1997;22:451–456
23 Palmer AK, Werner FW. Biomechanics of the distal radioulnar joint. Clin Orthop Relat Res 1984;187(187):26–35
24 Sagerman SD, Zogby RG, Palmer AK, Werner FW, Fortino MD. Relative articular inclination of the distal radioulnar joint: a radiographic study. J Hand Surg Am 1995;20(4):597–601
25 Suzuki M, Kurimoto S, Shinohara T, Tatebe M, Imaeda T, Hirata H. Development and validation of an illustrated questionnaire to evaluate disabilities of the upper limb. J Bone Joint Surg Br 2010; 92(7):963–969
26 Nakamura R, Hori M, Imamura T, Horii E, Miura T. Method for measurement and evaluation of carpal bone angles. J Hand Surg Am 1989;14(2 Pt 2):412–416
27 Siddiqui O, Ali MW. A comparison of the random-effects pattern mixture model with last-observation-carried-forward (LOCF) analysis in longitudinal clinical trials with dropouts. J Biopharm Stat 1998;8(4):545–563
28 Chung KC, Zimmerman NB, Travis MT. Wrist arthrography versus arthroscopy: a comparative study of 150 cases. J Hand Surg Am 1996;21(4):591–594
29 Yamamoto M, Koh S, Tatebe M, et al. Importance of distal radioulnar joint arthroscopy for evaluating the triangular fibrocartilage complex. J Orthop Sci 2010;15(2):210–215
30 Adams BD. Distal radioulnar joint instability. In: Wolfe SW, Hotchkiss RN, Pederson WC, Kozin SH, eds. Operative Hand Surgery. 6th ed. New York, NY: Churchill Livingstone; 2011:523–560
31 Tatebe M, Shinohara T, Okui N, Yamamoto M, Hirata H, Imaeda T. Clinical, radiographic, and arthroscopic outcomes after ulnar shortening osteotomy: a long-term follow-up study. J Hand Surg Am 2012;37(12):2468–2474
32 Friedman SL, Palmer AK, Short WH, Levinsohn EM, Halperin LS. The change in ulnar variance with grip. J Hand Surg Am 1993; 18(4):713–716
33 Palmer AK, Glisson RR, Werner FW. Relationship between ulnar variance and triangular fibrocartilage complex thickness. J Hand Surg Am 1984;9(5):681–682
34 Tomaino MM. Results of the wafer procedure for ulnar impaction syndrome in the ulnar negative and neutral wrist. J Hand Surg [Br] 1999;24(6):671–675
35 Tatebe M, Horii E, Nakao E, et al. Repair of the triangular fibrocartilage complex after ulnar-shortening osteotomy: second-look arthroscopy. J Hand Surg Am 2007;32(4):445–449
36 Baek GH, Chung MS, Lee YH, Gong HS, Lee S, Kim HH. Ulnar shortening osteotomy in idiopathic ulnar impaction syndrome. J Bone Joint Surg Am 2005;87(12):2649–2654

37 Iwasaki N, Ishikawa J, Kato H, Minami M, Minami A. Factors affecting results of ulnar shortening for ulnar impaction syndrome. Clin Orthop Relat Res 2007;465:215–219
38 Fricker R, Pfeiffer KM, Troeger H. Ulnar shortening osteotomy in posttraumatic ulnar impaction syndrome. Arch Orthop Trauma Surg 1996;115(3-4):158–161
39 Rayhack JM. Technique of ulnar shortening. Tech Hand Up Extrem Surg 2007;11(1):57–65
40 Darlis NA, Ferraz IC, Kaufmann RW, Sotereanos DG. Step-cut distal ulnar-shortening osteotomy. J Hand Surg Am 2005;30(5):943–948
41 Urita A, Iwasaki N, Kondo M, Nishio Y, Kamishima T, Minami A. Effect of low-intensity pulsed ultrasound on bone healing at osteotomy sites after forearm bone shortening. J Hand Surg Am 2013;38(3):498–503
42 Deluca PA, Lindsey RW, Ruwe PA. Refracture of bones of the forearm after the removal of compression plates. J Bone Joint Surg Am 1988;70(9):1372–1376
43 Beaupre GS, Csongradi JJ. Refracture risk after plate removal in the forearm. J Orthop Trauma 1996;10(2):87–92
44 Werner FW, Palmer AK, Fortino MD, Short WH. Force transmission through the distal ulna: effect of ulnar variance, lunate fossa angulation, and radial and palmar tilt of the distal radius. J Hand Surg Am 1992;17(3):423–428
45 Pomerance J. Plate removal after ulnar-shortening osteotomy. J Hand Surg Am 2005;30(5):949–953
46 Isaacs J, Howard SB, Gulkin D. A prospective study on the initial results of a low profile ulna shortening osteotomy system. Hand (NY) 2010;5(2):148–154
47 Fulton C, Grewal R, Faber KJ, Roth J, Gan BS. Outcome analysis of ulnar shortening osteotomy for ulnar impaction syndrome. Can J Plast Surg 2012;20(1):e1–e5
48 Barry JA, Macksoud WS. Cartilage-retaining wafer resection osteotomy of the distal ulna. Clin Orthop Relat Res 2008;466(2):396–401